MOBILE FLOW CONTROL ELEMENTS FOR HIGH-PRESSURE MICRO-ANALYTICAL SYSTEMS FABRICATED USING *IN-SITU* POLYMERIZATION

J. E. Rehm[*†], T. J. Shepodd, E. F. Hasselbrink**
Sandia National Laboratories, Livermore, CA, USA

* Eksigent Technologies, 2021 Las Positas Court Suite 161, Livermore, CA, USA
[**] Dept. Mechanical Engineering, University of Michigan, MI USA
[†]jerehm@eksigent.com

Abstract

A method for rapidly fabricating a family of robust fluid control elements in microfluidic channels is presented. The polymer devices are lithographically defined *in situ* in glass microfluidic channels in a few seconds on a benchtop. The devices are capable of controlling fluid flow in microchannels at pressures exceeding 5000 psi (340 bar) and can be actuated in milliseconds. In this work we demonstrate chip-based devices, including a piston, check-valve, and a 10 nanoliter pipette.

Keywords: microvalve, microfluidic control, microfluidics, polymer, valve

1. Introduction

Integration and advanced functionality of μTAS have been fundamentally limited by the inability to incorporate fluid control devices with microfluidic channels. The problem is difficult because of the range of requirements for a practical microdevice: it may be required to provide excellent sealing against very high pressures or be compatible with electroosmotic flow (*e.g.*, nonconductive); at the same time, it must be relatively inexpensive and process-compatible. Although significant effort has been placed in developing microscale versions of traditional valves from an array of materials [1], recent work in ‘soft’ valves [2,3] appears promising. Here we present a simple and inexpensive means for making a new class of “soft” microscale flow control devices.

2. Fabrication

Devices are photo-polymerized inside an existing glass or silica microfluidic channel, where a monomer-solvent-initiator mixture has been introduced (Fig. 1). A typical formulation used in the examples presented here is as follows: 1,3 butanediol diacrylate and trifluoroethylacrylate (mixed 1:1) as the monomer (80%), 2-methoxyethanol, 1,4 dioxane, and 5 mM TRIS buffer (mixed 4:4:1) as the solvent (20%), and 2,2’-azobisisobutyronitrile (0.5 wt.%) as the photoinitiator. Cross-linking is initiated within a selected region of microchannel by UV exposure through a chrome mask (10-45 seconds from a 355 nm Nd:YAG laser at 1 mJ cm^{-2}/pulse, 10 Hz), with about 3μm resolution. Resolution is limited by the competition between radical diffusion and initiation/recombination reactions.

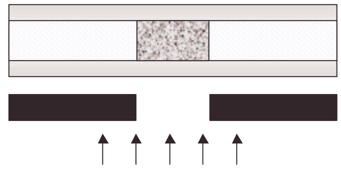

Figure 1. Channels filled with liquid monomer are exposed to a UV light source through a lithographic mask. Photo-polymerization is initiated in the exposed region.

The polymerized element does *not* adhere to the channel walls, creating a small "piston" that can be mobilized by applying pressure. Modifying the initial mixture allows the behavior and functionality of the device to be tailored to a specific application, as even modest variations in formulation can have dramatic effects on the polymer structure and its mechanical properties. In general, this method allows us to produce a polymeric monolith that conforms to the shape of the microchannel and does not bond to surrounding structures with excellent repeatability.

3. Experimental Results

Various combinations of polymer and channel geometry lead to a wide variety of devices. For example, Figure 2 shows a variable-area piston, which successfully seals against 10 bar of air pressure. Figure 3 shows a check-valve configuration, which only allows unidirectional flow due to the location of the piston relative to a bypass channel.

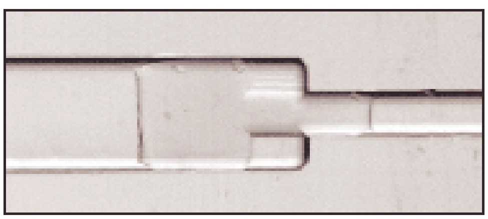

Figure 2. A polymer piston in a microfluidic channel (150 μm wide, narrowing to 50 μm wide, 25 μm. deep). The piston is displaced slightly to the left of its sealing surface. Pistons have been demonstrated to seal against high pressures in liquid and gas environments.

These closed-cell structures have high compressive strength, yet are flexible enough to negotiate 90° turns without damage. Compressive tests indicate most elements have a modulus of elasticity similar to a common rubber stopper (0.01-0.1 GN/m^2). Initial pressure and leakage tests have been performed in silica capillaries and glass chips in a configuration similar to that shown in Fig. 3. Maximum pressures exceed 340 bar, and actuation times are less than 1 video frame (33 msec). Actuation pressure can be less than 1 psi, depending strongly on UV exposure during polymerization as shown in Fig. 4. The leakage rates of these devices vary between 0-50 pL/min over a wide range of pressures (0-

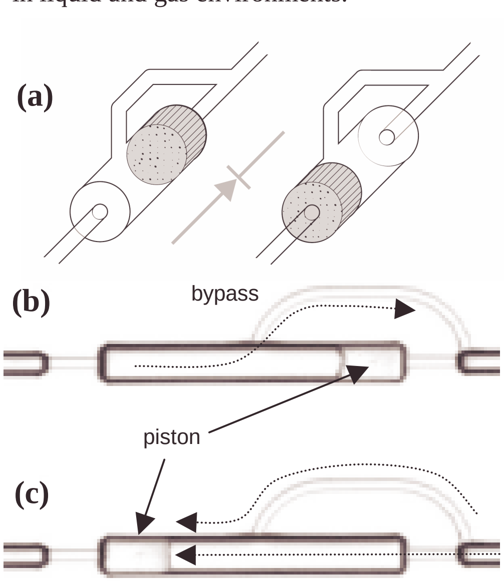

Figure 3. On-chip check valve. (a) Schematic of valve architecture. Both glass wafer surfaces are HF etched to produce interconnecting channels of concentric cylinders when bonded. (b) Flow from left-to-right bypasses the piston seated against the right stop. (c) Flow in opposite direction is prevented when the piston seals against the left stop, 'checking' the flow. Cylinder diameter is 100 μm with 25 μm weirs. Flow direction is indicated by dashed lines.

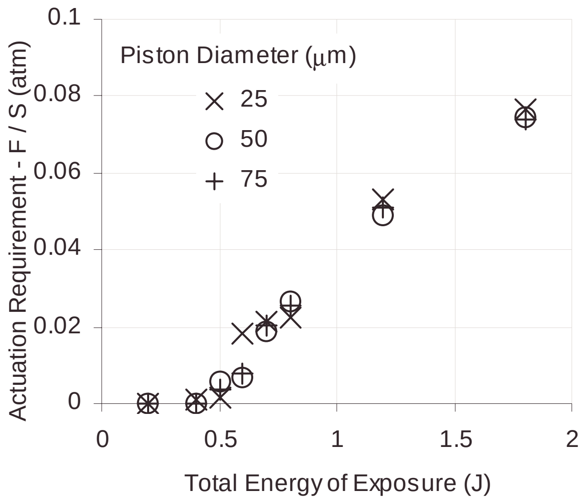

Figure 4. Actuation requirements (force divided by surface area in contact with channel wall) for polymer pistons as a function of initiation energy. Element length is 1 mm.

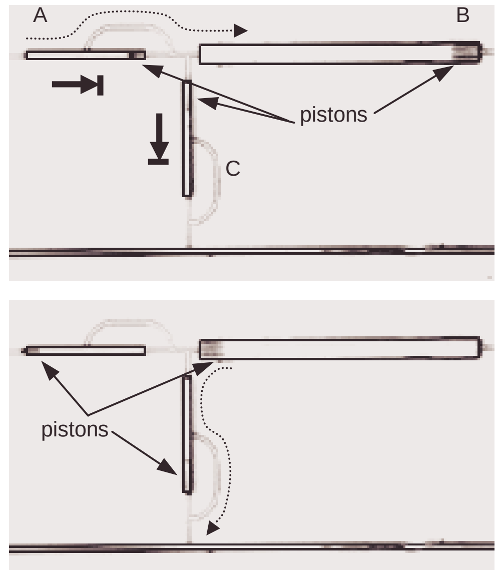

Figure 5. A 10 nanoliter pipette for aliquoting sample into a channel. Dashed lines indicate fluid flow direction. *Top:* Suction is applied at inlet B and the piston in cylinder B moves to the right (while drawing sample from inlet A through open check valve) until the stop is reached. Valve C remains closed. *Bottom:* Pressure is applied at inlet B; A closes, C opens, and the fluid in cylinder B is injected into the channel.

300 bar). As the pressure increases, the sealing behavior improves (leakage decreases), as the polymer deforms to compensate for imperfections in the sealing surface.

Complex functions can be performed with a sequence of dependent elements as shown in Fig. 5, where a piston combined with two check-valves form a pipette, used to aliquot a 10 nanoliter sample volume into a running LC column. A wide range of pipette sample volumes (picoliter to microliter) can be defined by chip geometry.

5. Conclusions

A method of fabricating a family of fluid control elements has been developed that enables the development of highly integrated high-pressure microfluidic systems. These devices are process-compatible with existing chip architectures that allow paths for optical access. The devices are fabricated rapidly and inexpensively, outside of a clean-room, in a single post-microfabrication step.

References

1. Shoji, S., and Esashi, M., Microflow Devices and Systems, *J. Micromech. Microeng.* 4(4), 1994, 157-171.
2. Beebe, D. J., Functional hydrogel structures for autonomous flow control inside microfluidic channels, *Nature* 404, 2000, 588-589.
3. Unger et al., Monolithic microfabricated valves and pumps by multilayer soft lithography, *Science* 288, 2000, 113-116.

This work was supported by the LDRD program at Sandia National Laboratories.
Sandia is operated for the United States Department of Energy under contract DE-AC04-94AL85000.